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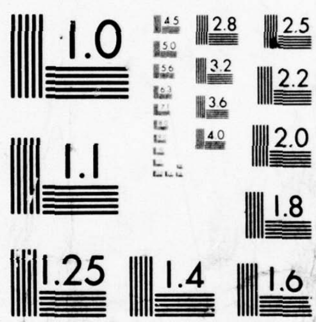

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A SURVEY OF CONSIDERATIONS FOR SOLAR ENERGY FACILITY APPLICATIONS

DECEMBER 1977

CEEDO

FINAL REPORT

CIVIL AND ENVIRONMENTAL
ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE SYSTEMS COMMAND)
TYNDALL AIR FORCE BASE
FLORIDA 32403

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The purpose of this report is to provide Air Force civil engineers some useful information for the planning and programming of solar energy systems to satisfy facility energy requirements. This report has been prepared in response to the belief that considerable interest in solar energy system technology, as well as other alternate energy schemes, is increasing at a rapid pace in the Air Force. A considerable effort is devoted to appraising the current status of fossil fuel energy resources in order to establish the need for expanded work in developing solar energy technology. The current and potential areas of → (over)

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application of solar energy technology are described with special attention devoted to space heating. Additionally, environmental considerations of solar energy technology are described along with the current Air Force solar energy program. This report concludes with some suggestions for establishing a solar energy program on an individual or installation basis.

PREFACE

This report was prepared by Major Marshall W. Nay, Jr., USAF, while enrolled in the Air Command and Staff College. It was submitted to the Civil and Environmental Engineering Development Office (CEEDO) for publication. The CEEDO project officer was 2d Lt Richard A. Shutt.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

Today it is difficult to pick up a magazine or newspaper and not find an article on solar energy. Most of these articles present solar energy in a very positive manner. The result is that more of us are beginning to wonder if perhaps solar energy is not the panacea for all of our energy problems. Certainly, solar energy has many applications today in many geographic areas under certain conditions. Many technical applications have been demonstrated repeatedly and a commercial solar energy industry is emerging. The two current shortcomings facing commercial development are the high cost of solar energy systems relative to fossil fuel systems and a definition of the useful life of solar energy systems in the field under consumer conditions. Nevertheless, military engineers should begin to seriously consider solar energy applications for future projects.

If you are planning and programming a solar energy system at your base to satisfy some of your facility energy requirements, you may find the information presented here beneficial. If you do not have such a project application under consideration at this time, perhaps the information presented here will provide you with some ideas. Nevertheless, whether or not you are developing a contingency plan, responding to a scenario involving a shortfall of funds or raw energy, or implementing a demonstration program, there are many factors that you will want to consider. Hopefully, those factors will be presented here.

Among the difficulties facing military engineers today in the planning and programming of energy for our facilities is the uncertainty of the future. The biggest concerns are what will be the energy base of the future and what will be the user constraints. The best estimate for the sake of military planning for the next 25 years is that our energy base will continue to be fossil fuels. This base, however, will probably shift from one of predominantly oil and natural gas to one of coal and coal byproducts supplemented by some exotic energy sources such as nuclear and solar energy. Although a national energy policy is emerging now, user constraints still remain uncertain.

SECTION II

THE ENERGY SITUATION

A few years ago, we as a nation established the goal of "energy independence." We desired to be totally self-sufficient for our energy needs by the 1980s. It would now appear that our national energy policy, although still stressing independence, will strive simply to make us less dependent on foreign energy sources, and in turn, more self-sufficient. For the immediate future, we will continue to import much of our energy. Hopefully, we will become adequately self-sufficient to be able to satisfy our emergency and wartime requirements and become less vulnerable to external economic sanctions and embargoes.

Ever since the Industrial Revolution, society has evolved around the premise that the power of a country is related to the amount of energy it consumes rather than the amount of raw energy sequestered in the natural resources confined within its territorial borders. The present balance of world power has thus resulted. The dichotomy that has developed is that many of the most powerful countries now rely heavily on imported energy. Now we are entering a period of history that may be referred to as the Post-Industrial Period. Colonialism is fading and the third world nations are emerging. Suddenly, the opportunity for a shift in the balance of world power in favor of those countries that have ample territorially-confined energy resources becomes a realistic alternative. The Soviet Union is energy self-sufficient, the United States is not (Reference 1). The Arab Oil Embargo of October 1973 to February 1974 illustrated this to every American (Reference 2). We suffered a shortfall of 1.9 million barrels of oil per day (MBPD), 12 percent of our national requirement. Consequently, a half a million Americans became unemployed and our gross national product declined by perhaps as much as 20 billion dollars.

As a nation, we have responded in a number of ways:

1. Energy conservation steps such as lowered thermostat settings, more building insulation, and increased mileage in automobiles have been applied.

2. Plans have been set in accordance with the Energy Policy and Conservation Act to stockpile a three-month supply of oil by 1982 (Reference 3).

3. Action has been taken to intensify development of our conventional fossil fuels (oil, natural gas, and coal) in order to increase domestic production.

4. Synthetic fuels from oil shale and coal have been developed in an exploratory manner in order to develop the required technologies.

5. Economic algorithms that dictate the distribution and consumption of fossil fuels have been closely reviewed and may soon undergo some major modifications.

6. Alternate energy sources such as solar energy have been developed in an exploratory manner in order to develop the required technologies.

7. The Federal government structure has been realigned in order to more effectively deal with energy issues. The Atomic Energy Commission was eliminated. In its place were created the Nuclear Regulatory Council, the Federal Energy Administration (Reference 4), and the Energy Research and Development Administration. Additional reorganization may occur in the future. (On 1 October 1977 the Department of Energy was formally organized.)

SECTION III

THE ENERGY DEMAND

At this time in history, the United States consumes about 83 quadrillion (10^{15}) BTUs of energy per year, which is roughly equivalent to 41 million barrels of oil per day. This consumption rate has been increasing approximately four percent annually for the past 20 years. Of this great amount, approximately 41 percent is consumed by industry, another 25 percent by transportation, another 20 percent by residences, and the remaining 14 percent by commercial businesses. Because of our keen interest in oil, the various contributors to our energy portfolio are often reported in terms of equivalent barrels of oil. Estimates of this information are contained in Table 1 (References 5 through 7).

TABLE 1. *ESTIMATED CURRENT US ENERGY CONSUMPTION*

Fuel	Amount (10^{15} BTU/Yr)	Equivalent MBPD	Percent
Oil	33.4	16.6	40.3
Natural Gas	22.6	11.3	27.3
Other Petrol. Prod.	4.4	2.2	5.3
Coal	16.0	8.0	19.3
Hydropower	3.0	1.5	3.6
Nuclear	3.5	1.7	4.2
	82.9	41.3	100.0

The shortfall in energy self-sufficiency occurs in the oil and natural gas category, with the more critical one being oil. The current world oil demand is approximately 57 MBPD (Reference 8). The United States accounts for 29 percent of this. Oil production capacity in the United States ranges between 8 and 10 MBPD. Currently it is 8.1 MBPD but is scheduled to increase by 1.2 MBPD when the Alaskan pipeline becomes operational (Reference 2). The difference of approximately 7 MBPD (42 percent) is imported, at an annual cost this year of 24 billion dollars (Reference 9), primarily from Organization of Petroleum Exporting Countries (OPEC).

At the national level the Air Force is an energy consumer of some consequence. It consumes about one percent of the energy used by the United States, a quantity equal to about half that consumed by the entire Department of Defense. The majority of this energy is used to support the flying mission. Air Force installation support requirements for the past few years have consumed about 200 trillion (10^{12}) BTUs of energy (197 trillion in FY76), which represents about 25 percent of the Air Force total. About half this energy is consumed as electricity, another quarter as oil, and the remainder as a combination of gas, coal, and steam. The cost of this in FY76 was 350 million dollars. This represents a twofold increase since FY73, in spite of a 17 percent reduction in consumption (References 10 through 13).

SECTION IV

THE FUTURE AND FOSSIL FUELS

The nonrenewable status of our fossil fuel supplies warrants asking how long they will last. As you can imagine, this question has been asked frequently in recent months. Numerous scenarios and some sophisticated models have been developed. For our purposes we will take a simplistic, but pragmatic, approach to the problem.

Table 2 is an estimate of the world supply of conventional fossil fuels. How much of it is recoverable will depend upon cost, intended use, and our future technologies (References 6, 14 through 16).

TABLE 2. ESTIMATED WORLD CONVENTIONAL FOSSIL FUEL SUPPLIES

Type	Quantity	Conversion	$Q(10^{18}$ BTU)	Percent
Coal	7500 billion tons	26.3×10^6 BTU/ton	197.3	95.0
Oil	1700 billion barrels	5.5×10^6 BTU/barrel	9.4	4.5
Gas	900 trillion cubic feet	1030 BTU/ft^3	0.9	0.5
			207.6	100.0

The United States, comprising five percent of the world's population, accounts for one-third of the world's annual energy consumption of 250 quadrillion BTUs. How long then will the world supply of fossil fuel last?

One extreme case might be to assume that the world energy consumption rate remains constant at the current rate of 250 quadrillion BTUs per year. Under this condition the fossil fuel supplies would last about another 800 years. Another extreme, at the opposite end of the spectrum, would be to assume that the world energy consumption rate will continue to increase at a rate of four percent annually. Then the supplies would only last about another 100 years.

Both these cases are highly unlikely, but at least they do establish some boundaries for long-term planning. Certainly, energy consumption rates are not going to remain constant. On the international scale, we must expect them to increase. After all, it is the goal of numerous people the world over to achieve the same living standards as Americans. Additionally, both cases assumed that full use of coal was to be made, which accounts for 95 percent of fossil fuels. Today, in actual consumption coal accounts for only 20 percent of utilized energy. At this time the world energy economy is deeply committed to oil.

Table 3 is an estimate of proven/potential world petroleum reserves (Reference 16). Two facts should startle you: first, the small amount of oil that the United States possesses; and second, the great amount (almost 60 percent) of oil that the Mideast and Communist bloc countries possess in aggregate. As for how long this supply will last, best estimates are about 80 years. Current world production is about 57 MBPD, with OPEC accounting for about 30 MBPD. However, rather than applying this demand uniformly to the available supply, current predictions are that production will increase rapidly, peak off in the 1990s, and then decline drastically (Reference 2). This prediction may not account for actions with the Communist bloc. One estimate shows them producing about 10 MBPD and consuming about 9 MBPD (Reference 1). At this rate, and with their reserves, they may be the only geopolitical entity left with oil reserves in the next century. Much of this, of course, is dependent on whether or not they are able to allocate the necessary capital, expertise, and technology to develop their Siberian energy resources. If not, they may cease to be energy self-sufficient.

TABLE 3. ESTIMATED WORLD PETROLEUM RESERVES

Country/Area	Quantity (billion barrels)	Percent
Canada	78	4.6
United States	127	7.5
Latin America	130	7.6
Western Europe	66	3.9
Africa	147	8.6
Antartica	20	1.2
Mideast	561	32.9
Communist Bloc	454	26.7
Far East	120	7.0
	1703	100.0

Nevertheless, between now and the 1990s most of the world will turn more and more to OPEC for its oil. Interestingly enough, oil production in OPEC is not uniform based on the reserves available. This information is shown in Table 4 (Reference 17).

Recent disagreements have arisen within OPEC concerning pricing and production policies. Some countries are facing financial problems and are anxious to obtain maximum revenues from their oil resource as soon as they can. Others are faced with the potential problem of producing all of their oil before their cartel partners do. As a result, some observers have predicted that OPEC may dissolve in the near future. This will probably not occur. The solidarity that has existed in the past within OPEC will probably continue into the future. Nevertheless, the situation does warrant monitoring as the military capabilities of

TABLE 4. ESTIMATED OPEC RANKING

Country	Production MBPD	Percent	Proven Reserves Billion Barrels	Percent
Saudia Arabia	8.4[a]	28	152	34
Iran	5.7	19	65	14
Venezuela	2.3	8	18	4
Kuwait	2.0	7	71	16
Iraq	2.0	7	34	8
Nigeria	2.0	7	20	4
U.A. Emirates	1.9	7	32	7
Libya	1.9	7	26	6
Indonesia	1.5	4	14	3
Others (Algeria, Qatar, Ecuador, and Gabon)	1.8	6	18	4
	29.5	100	450	100

[a] Scheduled to increase to 11.8 MBPD by December 1977.

some of the member countries located in the Middle East are increasing at a rapid rate. In conclusion, OPEC oil, particularly that from the Middle East, will play a role in the world energy economy for a long time to come.

The natural gas situation in the United States is as bad as or worse than that of oil. Unlike oil, we do not import much natural gas. Other than some which we import from Canada, we produce our own. In the future, we can expect to receive less and less natural gas from Canada. In addition, the hope of importing liquified natural gas in specially built tankers has not materialized. For the future we will have to be totally self-reliant.

Although our proven reserves are the lowest they have ever been, this does not mean that we have run out of natural gas. Economic constraints have precluded a concerted effort to develop it. Natural gas is not distributed uniformly across the nation. Texas, Louisiana, Oklahoma, and New Mexico account for most of our gas production. As a result, we have an interstate logistics system. In order to protect the private sector consumer from paying for excessive profits, the Federal Power Commission has for years regulated the wellhead price of natural gas destined for interstate shipment. The prices that have now resulted are considered to be quite low. If you will compare the unit energy cost of natural gas in your geographic area (if it is derived from an interstate source) with its competitors such as fuel oil or electricity, you will find that natural gas is a significant bargain by a factor of at least two or three. Consequently, natural gas suppliers have felt for many years that there was insufficient profit margin for them to vigorously pursue the exploration for new natural gas wells for interstate sales. As a result, United States natural gas reserves are declining.

Compounding the problem are the intrastate gas lines. These handle natural gas that is both produced and sold within the same state. The Federal Power Commission does not regulate the price of this gas. As you might expect, its price is considerably more. Because of the geographically variable as well as dynamic nature of natural gas prices, it would serve no purpose to quote any here. However, intrastate gas prices are often two to three times those of interstate gas prices and probably more closely represent their comparative thermodynamic value.

Natural gas is primarily used for space heating today. That which is used for residences has priority over that which is used for industries. As we witnessed this past winter in situations involving gas shortages, the industries are shut off first. The results are lost jobs, a depressed economy, and the inability to pay the bill for the gas used in residences. Such a vicious cycle has serious socio-economic effects and cannot be tolerated. Pursuant to this, we can expect to see the price of natural gas increase substantially (perhaps even be deregulated). The overall effect will be increased exploratory work in the fields to find new sources and an increase in our natural gas reserves. This will only be a temporary solution, however. Unless technological breakthroughs such as coal gasification are seriously pursued, natural gas, just like oil, will probably peak and then decline.

Now that the fossil fuel reserves have been examined in a macro sense, with some specific considerations to the United States, we will look specifically at United States fossil fuel reserves. These are shown in Table 5. When the US demand of 83 x 10^{15} BTUs is applied against these conventional fossil fuel supplies, there appears to be no problem.

TABLE 5. ESTIMATED US CONVENTIONAL FOSSIL FUEL SUPPLIES (REFERENCES 6 AND 18)

Type	Quantity	Conversion	Q(10^{18}BTU)	Percent
Coal	350 billion tons	26.3x10^6BTU/ton	9.2	90.2
Oil	127 billion barrels	5.5x10^6BTU/barrel	0.7	6.9
Gas	250 trillion cubic ft.	1030 BTU/ft^3	0.3	2.9
			10.2	100.0

The real problem is that we have not been using our fossil fuels in a wise manner. Our coal reserves account for 90 percent of our available energy reserves, but we are using these reserves to provide for only 20 percent of our energy utilized. We have relied too heavily on oil and natural gas for our energy (73 percent) and now we must rely on imports (42 percent) to sustain ourselves.

SECTION V

SOME ENERGY CONCLUSIONS

What can we expect to see in the future? We do have the capability to be energy independent. However, it would not only be very costly, but it would also take a very long time to accomplish. Instead, we can expect to see a national energy policy that complements our economic foreign policy of international resource interdependence. As previously stated, we will try to become less dependent on foreign energy sources. For the next 25 years we can expect to continue to rely heavily on oil and natural gas. However, during this period we will probably begin to shift to an energy economy heavily dependent upon our greatest fossil fuel resource, coal. This will require a significant investment for two reasons. First, there will be a logistics problem. To properly use our coal resource, we will have to fully develop our western mines which are hundreds of miles from the points of consumption. The Alaskan coal resources that are now being defined are, of course, even further. Secondly, some of our coal will be converted, along with our oil shale deposits, to synthetic fuels. These synthetic fuels may fill the gap when our current oil and gas supplies peak and then decline. The technology to do this exists, but it has not been fully developed. Finally, there are some hopes that additional natural gas can be generated in sufficient quantity to economically justify the anaerobic digestion of organic matter such as animal wastes generated at feedlots or from domestic sewage.

The development of an energy self-sufficiency program is of the same order of importance to the United States as its strategic defense program of deterrence. Rather than choosing to invest our total strategic weapons capability into one type of weapon system, we chose the

Triad. This provides us the required flexible response to a wide range of contingencies and at the same time guards against the probable obsolescence that a technological advancement might generate. We should not expect that our national energy program of the future would be any different.

We should not rely solely on shifting our major reliance from one form of fossil fuels to another. In addition to shifting from our reliance on oil and natural gas to coal in the future, we will also shift a part of our reliance to nuclear energy and solar energy. This will give us the similar benefits of our strategic defense Triad. The percentile distribution among these three energy sources, and perhaps others, is difficult to predict and will in the end be determined by prevailing market conditions. Probably coal will account for the majority of our energy consumption, perhaps well in excess of 50 percent. The remainder may be equally split between nuclear energy and solar energy.

We have now reviewed the energy situation as it exists worldwide, nationally, and for the Air Force. We have identified the problem and have tried to optimistically suggest a solution. The next 15 to 25 years will be very critical. Outlining a solution to the problem is one thing; implementing it is another. We must be careful to move along at the right pace so we do not disrupt the sensitive balance of our own economy or world peace.

We recognize now that solar energy will play a significant role in our national energy program of the future. It is now time for the military to start planning and programming solar energy systems for some of its future facilities. Perhaps we can set an example here as we have done in environmental protection for the rest of the nation. To do this, we must understand the basics of solar energy, how it may be applied, the current state of its technology, and where it may be applied. Finally, we should know to whom to turn for help and information.

SECTION VI

AVAILABLE SOLAR ENERGY

All of us take that fiery orange ball in the sky for granted. Although 93 million miles away, the sun provides all of our energy. This energy is received in the form of electromagnetic radiation which is the product of nuclear fusion. The intensity of this radiation as it reaches the earth's atmosphere is considered to be constant at 428 BTU/ft^2-hr (in a horizontal surface) (Reference 19). Nevertheless, the amount of energy that actually reaches the biosphere, where it may be potentially used by man, is dependent upon many variables. In this regard, the two most important variables are the atmosphere that this radiation must pass through and the time dependent sun-earth relationships. With regard to the magnitude of energy received, it is tremendous. Its magnitude can be put in perspective when it is compared to the current estimated annual world energy demand. As previously mentioned, this demand is estimated to be 250 quadrillion BTUs. One estimate of the amount of solar energy striking only land masses is 830 quadrillion BTUs (Reference 20). Often the problem is that this energy is not sufficiently concentrated to satisfy many of man's needs. However, in many instances technology can overcome this. The final point here is for us to appreciate the tremendous amount of raw energy available.

The manner in which the atmosphere controls the amount of radiation that strikes the earth must be considered (Reference 21). This subject is important with regard to long term environmental considerations. About 30 percent of the solar radiation that strikes the earth is scattered back to the universe by atmospheric dusts, water vapor, and other reflective material. Together they are referred to as the earth's *albedo*. *One popular theory* would explain the relative cooling of the earth's atmosphere as a result of an increase in the albedo. This theory is referred to as the Ice Box Effect (Reference 22).

Another 20 percent is absorbed directly by atmospheric constituents and heats up the atmosphere. About three percent of this is accounted for by the absorption by the ozone layer of the penetrating shortwave (<0.3 microns) ultraviolet radiation that can cause skin cancer. The remaining 17 percent is accounted for by the absorption by water vapor and carbon dioxide of the longwave (>0.7 microns) infrared radiation. The result is that about 50 percent of the electromagnetic radiation in the visible portion of the spectrum (0.3 to 0.7 microns) enters the biosphere and strikes the earth's surface. Most of it is absorbed and reradiated as heat. Less than one percent is fixed by photosynthesis.

Thus the solar constant of 428 BTU/ft^2-hr is substantially reduced as it reaches the surface of the earth. Its value is dependent on latitude, time of the year, altitude, and local atmospheric conditions. The total radiation received, referred to often as solar insolation, is composed of direct or beam radiation and diffuse radiation. Beam radiation is received directly from the sun without any change of direction and accounts for the majority of the radiation. Diffuse radiation is radiation that has undergone a change in direction via reflection off of a particle, but has not had its wavelength affected.

There are numerous charts of the United States available today containing information on incident solar radiation. Referred to as Isohelidynamic charts, they are contour plotted normally by month of the year. These charts should be used cautiously as often they do not consider local atmospheric conditions that might be caused by local air pollution. Perhaps their greatest value is in support of initial planning actions.

Two instruments are readily available today that can accurately measure solar insolation. These two instruments are the pyranometer and pyroheliometer. The pyranometer measures total radiation, and the pyroheliometer measures beam radiation. With the renewed interest in solar energy that has occurred during the past three years, many such instruments have been installed around the country. Where available, this information should be actively used for engineering endeavors.

A pyranometer was installed at the Air Force Academy Solar Test House. Its initial measurements are contained in the first interim technical report, Solar Heating Retrofit of Military Family Housing (Reference 23). Solar insolation accumulated daily ranged from a low of 673 BTU/SF-day in December 1975 to a high of 1445 BTU/SF-day in April 1976. This value peaked finally in July 1976 at 1868 BTU/SF-day. The point here is that solar energy intensity as incident solar insolation varies widely not only from one location to another, but also at a single location as well. As a result of this, there are some locations better suited for solar energy applications than others. Recently, nine Air Force installations were hypothetically considered in this regard. This information is contained in technical report Alternative Energy Sources for United States Air Force Installations (Reference 6).

SECTION VII

SOLAR ENERGY APPLICATIONS BACKGROUND

The application of solar energy technology is not new. Archimedes used solar energy as a weapon of war, when in 215 BC he focused a large mirror on enemy ships and destroyed them. Other records of the use of solar energy in conjunction with lenses and mirrors appeared during the Renaissance. During the Industrial Revolution additional work on solar furnaces was accomplished with special applications for hot air and steam engines. These engines were, in turn, used to power printing presses and pumps. The interest in pump applications continued into this century. Early commercial applications were not successful as they could not compete economically with fossil fuels (References 24 and 25).

Interest was renewed in solar energy after World War II. In the United States, a small group of supporters maintained a solar energy program at the university and laboratory level and also constructed some solar heated houses. In Japan, Australia, and Israel parallel work on domestic solar hot water heaters progressed. In the mid-1950s a new dimension to the application of solar energy was added with the development of the silicon cell. This provided for the photovoltaic conversion of solar energy directly to electrical energy and has seen continued application in our space program.

In the early 1970s, in response to early shortfalls nationwide, renewed interest in solar energy occurred at an accelerated rate, supported by governmental agencies such as the National Science Foundation and now by the Energy Research and Development Administration. Throughout most of the country today there are a wide variety of active solar energy projects. Many of these are experimental prototypes and, as such, have received some media attention. Many are open to the public and are an excellent source of first hand knowledge. Today, solar energy technology has many possible applications, the economies of which must be considered case by case. One common application is heating water which may be used for domestic sources by itself or in a preheat mode. Additionally, it may be used to heat swimming pools. The most common application today is space heating - or more broadly put, space conditioning as technology has now made possible solar air conditioning as well. Nevertheless, solar space heating is by far the more common and will be discussed shortly. Another application for solar energy is to produce electric power either photovoltaicly or from solar generated steam. To summarize, the major applications of solar energy technology today are hot water heating for domestic or swimming pool applications; space conditioning, especially heating; and electric power production.

These three applications are by no means all inclusive. Solar energy may also be used for water desalinization. Another application is the drying of agricultural products. Associated with this agricultural application is bioconversion. Some examples of bioconversion are the cultivation of fast growing plants for the purpose of burning for heat and the fermentation of waste organic matter in order to generate methane gas.

One final application often associated with solar energy is wind energy. Often referred to as aeolian energy, it is associated with solar energy because the incoming solar radiation accounts for its generation. The energy derived is the kinetic energy resulting from the movement of air masses relative to a land station. This energy is converted directly to mechanical energy via windmill devices and can then be converted to electrical energy via a generator.

SECTION VIII

SPACE HEATING APPLICATIONS

Special attention will be devoted here to solar energy space heating applications because of the current interest. Such a system is composed of the solar collectors, thermal storage, heat delivery, and control subsystems. In your initial planning, there are a number of alternatives that will affect your project. Among these alternatives are the following: the type of solar collector to be used, the location of the collectors, the type of heating system, and the type of thermal storage system to be used. A key factor in selecting an alternative is the nature of the application of the solar energy space heating system. This application will either be new construction or retrofit (modification of an existing facility). The differences between the two with regard to solar energy applications, whether they be for space heating or something else, are significant. Most of the solar energy work done in the United States to date has been new construction. The Air Force, with a largely fixed real property base, is going to be more involved with retrofit solar energy applications. As a result, solar energy work accomplished in the private sector should be carefully analyzed before applying it against Air Force requirements.

If you are involved with a new construction application, the engineering job will probably be easier, less costly, and offer more design flexibility. It will be easier simply because you are starting from the ground up and will not have to work around restricting conditions. Perhaps the most restrictive condition is the roof, if you select it as the area to locate your solar collectors. An existing roof may have to be structurally stiffened to support the additional loading imposed by the solar collectors (typically 10 to 15 pounds per square foot). In addition, its pitch may have to be altered in order to achieve the necessary sun angle (typically the latitude plus 10 to 12 degrees from the horizontal) for winter maximization. In a new construction application these special requirements can be incorporated into the initial design. New construction applications also allow you to use solar collectors without backing insulation or surfacing because they become an integral part of the roof structure. In retrofit applications you have to use modular or self-contained solar collectors. The modular solar collectors cost one to two dollars more per square foot.

Even more flexibility may be achieved with the thermal storage system employed. Your choices are water, crushed rock, or eutectic salts. In a new construction application any of these three may be incorporated in the design. However, this becomes tenuous in a retrofit application. Consider hiding 20 tons of crushed rock near the mechanical room in an existing Government family housing unit - you may be limited to a buried water storage tank.

Eutectic salts have much promise but have not shown sufficient life cycling capability and are expensive. Whereas the water and crushed rock store the thermal energy collected as sensible heat, the eutectic salts store it as latent heat. The eutectic salts release their stored thermal energy by undergoing a phase change. They are selected and configured to revert between a liquid and a solid at a specific temperature engineered for the solar energy system they are to support. As the thermal energy is stored in their molecular structure, they enter the liquid phase. Later, when it is necessary to recover this stored energy, a phase change is induced. As the salts enter the solid phase, they give up their stored thermal energy. All indications at this time are that the present salts cycle through a limited number of phase changes and then begin to break down. Until more work at the experimental level under actual field conditions can be accomplished, this storage system should be avoided. Some houses in the ERDA/DOD program will use eutectic salts to provide more data under true field conditions.

The selection of the heating system to be employed may affect the project considerably because of the required operating temperature. Generally, the greater the operating temperature required, the greater are the demands placed upon the solar energy system. Certainly, extremely high temperatures can be achieved with a number of solar collectors today. However, this is often done at the expense of the mass flow rate of the working fluid. Thus, high temperatures can usually be achieved by very low mass flow rates. The trade-off is that to capture sufficient thermal energy for an application, the amount of solar collectors has to be greatly increased. The result is higher project capital costs. A typical radiative heating system might require water temperature in the 160 to 180^{O}F range, while a forced hot air system might require water temperature in the 110 to 130^{O}F range.

What about minimum water temperatures or air temperatures? Again, each case should be evaluated individually. Air blown directly on a person will feel cool if it is less than body temperature. With this is mind, and recognizing that there will be some heat losses in the supply ductwork, a minimum temperature of 105^{O}F at the furnace bonnet would appear reasonable. Experimental work at the Air Force Academy Solar Test House, after a series of reiterations, verified this conclusion. If the standard delivery ducts could be replaced by diffuser grilles located so that they do not draft directly upon the occupants, lower temperatures, sufficient only to heat the room, should be used.

Of all the components that make up a solar energy system, the solar collector is the most important. A few years ago there were only a few solar collectors commercially available - today many are available. Last year the Energy Research and Development Administration in cooperation with the Department of Housing and Urban Development published the necessary sun angle (typically the latitude plus 10 to 12 degrees from the horizontal) for winter maximization. In a new construction application these special requirements can be incorporated into the initial design. New construction applications also allow you to use solar collectors without backing insulation or surfacing because they become an integral part of the roof structure. In retrofit applications you have to use modular or self-contained solar collectors. The modular solar collectors cost one to two dollars more per square foot.

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By far, the more popular collector is the flat plate collector. In its modular form, the flat plate solar collector is similar to a storm window. Built in a structural frame of anodized aluminum, stainless steel, or perhaps wood, its outside layer is composed of glass or plastic. The purpose of the glass or plastic is to act as an insulator. Although translucent to shortwave radiation, they are opaque to longwave radiation; i.e., they let the light pass through to strike the absorber surface, but they prevent the reradiated heat from escaping. Today, many collectors feature multiple layers of glass in order to improve their thermodynamic performance. However, there is a trade-off here. By the very nature of the molecular structure of the glass, not all incident light is allowed to pass through. Two layers of glass, referred to as double glazing, will allow about three-fourths of the incident light to pass through, and should be sufficient for normal facility applications. The inside layer, the collector surface itself, may be composed of steel, copper, or aluminum. The back of the collector underneath the collector surface is heavily insulated. The collector surface may be treated with a flat black paint or a more selective surface coating that absorbs a wider portion of the radiation spectrum. This surface absorbs much of the radiation incident upon it and reradiates much of it as longwave radiation. Because the exterior surface is glass which is opaque to longwave radiation, the ambient temperature of the dead air space and the collector surface increases significantly. Working fluids are pumped through or over the surface of the collector absorbing surface to carry away the excess heat and attempt to return the system to equilibrium.

Most of the working fluids are high specific heat liquids (water, water/ethylene glycol, trade-named alkyl polyaromatics). Air may also be used as the working fluid in conjunction with crushed rock thermal storage. If liquids are used, flat plate solar collectors may be further classified as either high performance or low performance solar collectors. In high performance solar collectors, the working fluid is passed across the absorber surface of the collector plate through conduits under pressure. In low performance solar collectors, the working fluid is allowed to cascade down the surface of the absorber plate under gravitational influence alone. The high performance solar collectors are able to collect thermal energy at a higher temperature than the low performance solar collectors and thus may have a greater variety of applications. Perhaps offsetting this advantage, however, is that the high performance solar collectors require a more sophisticated supporting hydraulic system. Operating pressures of 30 to 50 pounds per square inch gauge or more can be expected with the high performance solar collectors and care must be taken to insure uniform flow distribution to avoid problems such as vapor locking.

The choice of the proper solar collector for the application being considered is probably the most important design decision that must be made. Not only can it affect the thermodynamic success of the project, but it will also impact greatly on project costs, as the solar collectors may represent as much as half of a project's cost. The unit costs of solar collectors vary widely. Typical high performance solar collectors' unit costs are 10 to 12 dollars per square foot. Low performance solar collectors may be four to six dollars per square foot. Some of the more exotic flat plate solar collectors may cost considerably more.

Because of the significant impact that solar collectors may have on overall project cost and performance, a great deal of research and development work is underway. The general goal is to significantly lessen the cost of solar collectors so that solar energy system use will become more widespread. The opportunity of this occurring is probably marginal. Many companies associated with this are high technology companies. Much work has been centered on improving the electromagnetic radiation absorptivity and lessening the corollary emissivity of solar collector absorber surfaces by developing selective surfaces. This action results in greater thermodynamic performance, but may not always be well suited for general domestic purposes. The reason is that some selective surfaces may be overly sensitive to high temperatures and may break down or lose their effectiveness. If this were the case, for them to maintain their integrity they would have to be covered in the field when not in use. Action of this nature would not be practical for family housing and other similar applications. In selecting a solar collector, special attention should be paid to the nature of the absorber surface. Choice of a selective surface should be carefully weighed and all information pertaining to its stability during periods of non-use when exposed to the sun should be determined. Simple surface coatings of a flat black paint will probably be sufficient for most military real property applications.

SECTION IX

A REPRESENTATIVE SOLAR HEATED HOUSE

A representative solar heated house might fit the following description. Located in the middle latitudes in the United States, it is a single story, three bedroom, one and a half bath home with about 1600 square feet of floor space. Before the solar energy system was incorporated, all reasonable energy conservation measures to reduce the heat load were used. This reduced the amount of solar collectors that were required and thus measurably lowered the initial cost of the solar energy system.

Nevertheless, this particular hypothetical location experiences about 6000 heating degree-days annually, and, based on the lowest outside temperature anticipated, the design heating load for the house is approximately 34,000 BTUs per hour. Standards require that the heating system be designed against this requirement. However, actual experience in the area shows that the lowest design outside temperature is seldom experienced and that the average outside temperature during the heating season is greater. Consequently, the average heating load for the house is approximately 22,000 BTUs per hour. The solar insolation received ranges from a low of 450 BTUs per square foot per day in December to a high of 1700 in June. The heating season typically runs from October to May.

The heating system is a combination of a solar energy heating system complemented by a natural gas fired furnace. The method of heat delivery is forced hot air. The solar energy system is integrated with the furnace and forced hot air delivery system by means of a heat exchanger installed in the furnace plenum. Flat plate solar collectors, located on the roof with tilt angles of 50 degrees, are used for collection in conjunction with a buried water storage tank for thermal storage.

Assuming this is a retrofit system, modular solar collectors with nominal dimensions of four by eight feet are used. Hypothetically, perhaps 15 of these solar collectors (480 square feet) with 600 to 1000 gallons of storage capacity might be typical for this application.

How well might such a system work? To provide heat for the house, the minimum storage temperature of the water must be no lower than 115°F. Thus, accounting for some heat losses, the minimum temperature delivered to the house will be about 105°F. The solar collectors, working in concert with the thermal storage tank, will probably have an overall thermodynamic operating efficiency of about 50 percent. The amount of the heat load this particular solar energy system would satisfy would vary monthly. Nevertheless, it would probably satisfy about a third of the design heat load and about half the actual heat load during the heating season.

What might this representative retrofit solar heating system cost? (Reference 28). If it is to be done by contract, the cost estimate as shown in Table 6 might be appropriate.

TABLE 6. PROBABLE COST ESTIMATE - RETROFIT

Contractor Site Mobilization	$ 500
Solar Collectors (Purchase Only) 480 SF at $12/SF is $5,760	5,800
Roof Modifications and Installation of Solar Collectors at $5/SF	2,400
Thermal Storage Tank, Installed in Place	1,000
Mechanical Equipment to Include Pumps, Piping, Heat Exchangers, and Insulation	1,000
Control System	500
Subtotal	$11,200
Contractor Contingencies, Overhead, and Profit (25%)	2,800
Grand Total	$14,000

If you are concerned about the cost or the system performance levels, you should make a series of reiterations until your own needs or constraints are satisfied. This example, although hypothetical, is realistic. In this regard, it highlights a major weakness of solar energy today, its high initial costs. The Air Force amortization periods have been determined, and they are shown in Table 7 (Reference 29).

TABLE 7. AMORTIZATION PERIODS FOR SOLAR ENERGY SYSTEMS

Hot Water Systems	10 years
Space Heating Systems	15 years
Space Heating and Hot Water Systems	20 years
Heating and Cooling Systems	25 years

Depending on the conventional fuel source that the solar energy system is offsetting, it may be somewhat difficult to justify a project. Of more concern is the uncertainty of the useful life of solar energy systems in the field under consumer conditions. Nevertheless, these are the guidelines for planning purposes. The costs of conventional systems are very dynamic, and in the future they will shift more in favor of solar energy systems. In the meantime, we can also expect to learn more information on the useful life of solar energy systems.

Two final notes on this representative solar heating system are necessary. The first note concerns cost limitations and the other contractor procurement mechanisms. There are limits imposed on how much money can be spent on military family housing projects. These limits are explained in AFR 86-1 (Reference 30). Because of the high initial costs associated with solar energy systems, these limits may be exceeded. If this is the case, methods to obtain waivers exist.

Procurement mechanisms offer two choices: Issuing a Request for Proposals (RFP) or issuing an Invitation for Bids (IFB). The IFB is the more common, but the RFP is a viable option because of the newness still associated with solar energy, especially if the project is related to an R&D program or demonstration program in which instrumentation or experimentation is involved. Additionally, contingencies may be partially abated if some of the solar energy system hardware is furnished, especially the solar collector panels.

SECTION X

SOLAR AIR CONDITIONING APPLICATIONS

Although not as common as solar space heating yet, the interest and technical capability to accomplish solar air conditioning are growing quickly. Solar air conditioning may be accomplished by itself or in combination with a solar space heating system. The air conditioning application may not only be applied to family housing but also, with equal potential for success, to large commercial buildings such as base exchanges. Solar air conditioning applications probably have as much potential as solar space heating applications.

Combination systems have a major advantage as they provide active use for the solar collectors on a year round basis. This full time dual purpose use helps not only in collector amortization but also eliminates the possible requirement of a passive solar collector protection system during periods of non-use, should the collectors' absorber surfaces be treated with a sensitive selective coating.

There are two common mechanical cycles currently available. One is the absorption cycle associated with earlier gas-fired refrigeration, and the other is the Rankine cycle associated with heat engines or heat pumps. In both cases, these cycles are activated by solar heated water. The absorption cycle requires solar heated water with a temperature of about 200°F. The exact temperature depends somewhat on the combination refrigerant-absorbent used. If a water-lithium bromide system is used, a temperature as low as 180°F is acceptable. However, if an ammonia-water system is used, a higher temperature of about 250°F is required. The refrigerant and absorbent selected are required to have a strong chemical mixing affinity for each other. The solar heated water drives much of the refrigerant out of solution as a vapor. The vapor, in turn, is separated, collected, cooled, and condensed, and then passed through an expansion valve as it passes into the system's absorber. Here it exists as a vapor at a low pressure and low temperature. It absorbs heat from the ambient environment and is brought to a boil. It is then mixed again with the cooled absorbent and pumped back to the beginning of the process to cycle again.

The Rankine cycle operates differently. It follows a vapor compression cycle, uses a refrigerant such as Freon, and has more latitude in its operation. To rely solely on solar energy, this cycle requires a solar heated water activation temperature upwards of 200°F. The solar heated water vaporizes the Freon which spins a turbine that drives an electrical generator to support a conventional air conditioning unit. Because of the nature of this system, much operating flexibility exists (References 6, 19, and 31).

In summarizing air conditioning applications, it must be realized that although great potential exists, there is much to be learned from actual field scale applications. From this aspect, solar space heating applications are much farther ahead. The biggest drawback is the high temperature solar heated water required to activate the system cycles. Although it is technically feasible to generate 200°F water temperatures with flat plate solar collectors, it is costly. Operating the collectors at this performance level substantially reduces their thermodynamic performance. Although little information on cost is currently available, costs of 1000 dollars per ton (12,000 BTUs per hour) have been reported for small scale applications (Reference 31).

One final note on the future application of solar energy systems use in conjunction with heat pumps for air conditioning applications is necessary. Heat pump use is growing again in popularity. These pumps appear to have overcome the maintenance problems that plagued them some years before and will probably see widespread use in the future.

Based on the Rankine cycle, heat pumps have the capability to interchange the functions of the evaporator and condensor and thus either heat or cool. Through the expenditure of energy from an external source, low level energy (low ambient temperature) is transformed to a higher or warmer level. In the summer, solar energy can usually input water of sufficient high temperature to activate the Rankine cycle to completion. If not, it can be augmented by conventional electric power. Its potential versatility in this regard is a major strength of such a combination system. In the winter months, the solar collectors provide a large heat source for the heat pump by way of their thermal storage tank. The heat pump evaporator will cool the thermal storage tank by absorbing heat from it at a low ambient temperature. Then it will amplify the heat through the compressor where it will be delivered to the area to be heated at a higher temperature. The greater the temperature in the thermal storage tank, the better will be the operating efficiency of the heat pump. Conversely, the lower the temperature in the thermal storage tank, the greater will be the thermodynamic performance of the solar collectors. A system such as this lends itself well to optimization. In conclusion, the potential for solar energy air conditioning may be best realized when done in conjunction with a heat pump. This may be especially the case when a heating requirement exists as well (References 6, 20, 31, and 32).

SECTION XI

PHOTOVOLTAIC APPLICATIONS

About one-third of the energy currently consumed in the United States is consumed as electricity. If a significant portion of this demand could be satisfied by non-fossil fuels, a tremendous savings in fossil fuels would be accrued by avoiding the inherently low thermo-mechanical efficiencies characteristic of thermal-electric power plants. Photovoltaic conversion may one day satisfy much of this demand.

Photovoltaic conversion transforms light energy directly to electrical energy without the benefit of any intermediate thermo-mechanical processes. The heart of such a system is the solar cell which is a solid state diode usually composed of silicon crystals. Recent developmental work has produced solar cells composed of cadmium sulfide and copper sulfide. These cells have operating efficiencies less than the silicon cells, but cost considerably less (Reference 33). Much more work needs to be accomplished before any valid comparisons can be made, but there is great potential.

When sunlight strikes the cell, the photons are absorbed and electrons are released, creating an electric field. When an electrical load is connected to the cell, the current produced is drawn off. Under conditions of maximum solar insolation, silicon cells may produce as much as 10 watts of electric power per square foot of solar cell area. More typical average production of power is closer to five watts per square foot. The unit weights of silicon solar cells will vary from 0.5 to 5 pounds per square foot (Reference 34).

Among the factors impeding the rapid development of photovoltaics for domestic applications is the extremely high cost. Typically, the current cost is 20 dollars per watt. A goal for the next 10 years is to reduce this cost to 0.50 dollar per watt. Among the factors attributable to this high cost is the cost of the silicon crystal. Current costs for the silicon crystal are 45 dollars per square foot for material alone. Material processing and fabrication add even more to the cost. The cadmium sulfide cells are projected to produce electricity at 0.30 dollar per watt within the next 10 years. Although their operating efficiencies are on the order of seven to eight percent compared to 10 to 12 percent for silicon cells, they are projected to cost considerably less (References 33 and 34).

Photovoltaic applications originated in the 1950s when the Bell Telephone Laboratories developed the silicon solar cell. Although the first application was in telephone amplifiers, the application of merit was the United States space program, starting with Vanguard I in 1958. The extreme success solar cells have had in this program is now history. Today there is a serious interest as to whether or not this success can be technologically transferred to the general public to support the significant consumer demand for electricity that exists. The two problems encountered in such a transfer of technology are high cost of the technology and the need to produce kilowatts of electric power as compared to watts of power.

An aggressive program to transfer this technology is currently underway. This program is in fact a demonstration program called the Military Applications of Photovoltaic Systems (MAPS). It is sponsored by the Energy Research and Development Administration in cooperation with the Federal Energy Administration (now the Department of Energy). Within the Department of Defense, the US Army Mobility Equipment Research and Development Command (MERADCOM), located at Fort Belvoir, Virginia, has been tasked with the prime coordinating and technical management responsibilities for MAPS. The Jet Propulsion Laboratory and the NASA Lewis Research Center are assisting in this endeavor.

The major purpose of MAPS is to apply photovoltaic technology to satisfy remote base and selected tactical and mobile applications. Hopefully, these military demonstration applications will not only produce additional technical improvements but also provide a sufficient economic market such that mass production of photovoltaic components will begin and thus lower the cost to private sector consumers. Projects within the program include a battery charger, a radio relay system, a telephone communications station, a water purification plant, and a radar system. Future plans call for a 60-kilowatt power station (References 34, 35, and 36).

SECTION XII

ENVIRONMENTAL CONSIDERATIONS

What are the environmental consequences of solar energy systems? This is a question that all of us must address sooner or later as we prepare environmental assessments for our projects. Certainly the overall effects of a solar energy system on the environment are positive. Nevertheless, recognizing that an environmental assessment must describe both the positive and negative environmental effects of a project as opposed to another document to support the project's approval, we must consider both the positive and negative environmental impacts of solar energy.

Solar energy is free. Is it? Suppose the energy and/or the utility companies get well into solar energy systems and install them in homes on a monopolistic lease basis as they do telephones under the auspices of local public service commissions. Solar energy could no longer be considered free. The socioeconomic impact could be significant. Perhaps this is remote, but some utility companies are investigating solar energy for residential applications (Reference 37).

The preceding scenario suggests environmental effects of solar energy systems that are at a macroscopic level and are not very applicable to military projects because of the lesser scope of work involved. One item certainly to be considered for smaller scale military projects is the benefits to be accrued by offsetting the use of conventional fossil fuels. These benefits would have to be determined case by case. They would involve a higher quality air achieved by not discharging air pollutants and also less environmental deterioration by avoiding the mining of the fossil fuels offset by the solar energy system. A positive socioeconomic effect would be accrued by such projects as they minimize the changes of economic disruption caused by another foreign oil embargo or "energy crisis."

Some offsetting negative effects could occur, however, with the thermal storage system and the working fluid employed. Consider, for instance, a hot water thermal storage tank. If the tank is filled with ambient tap water and the tank is constructed of reinforced concrete, unless special linings are used, the pH may rise drastically. This situation occurred at the Air Force Academy Solar Test House, resulting in a pH of between 10 and 11 (Reference 23). In addition, corrosion inhibitors may be used. Should the thermal storage tank crack or rupture, a leak or serious spill could occur (Reference 38). If the fluid should reach the natural drainage surrounding the home, it could have derogatory effects on the local terrestrial or aquatic ecologies because of its toxicity. Finally, should the contents from such a leak or rupture enter a sanitary sewer, the biological oxidation processes in the recipient sewage treatment plant could be upset. If the solar energy system is providing domestic hot water, even though a two loop system is provided for safety, a cross connection could have equal consequences.

Because of the possible damaging effects of freezing, water is normally not pumped through the solar collectors. Instead, a substitute working fluid such as a mixture of water and ethylene glycol or trade-named alkyl polyaromatic oils are used. A two loop system is used, complete with heat exchangers located in the thermal storage tank to avoid the high cost of filling the thermal storage tank with this substitute working fluid. With this arrangement, the thermal storage tank can be filled with tap water. The trade-off involved here is a guarantee against freezing but lower thermodynamic performance as these working fluids have a much lower specific heat (Reference 23). These working fluids could considerably compound the problem of a thermal storage tank leak because of their potential toxicity should they enter and mix with the water in the storage tank. Moreover, some of the aromatic based oils have a repugnant odor that could affect the liveability of a home should a leak develop.

After analyzing some of the environmental effects of solar energy systems to the air and water, we should consider some effects to the land. To reiterate, aside from the possibility of disruption of the terrestrial ecosystem due to leaks from the thermal storage tank previously mentioned, the most serious potential problem is the manner in which solar energy systems can affect the future use of adjacent land.

In the siting of the solar collectors of a solar energy system for a facility, there are three major factors to be considered. The first is azimuth. In the northern hemisphere this will be due south. The second is the required sun angle which will largely depend on the purpose which the system is to serve. The third factor is shadowing. The location of the collectors must be selected so no shadows from other structures or landscaping fall on the collectors. Conversely, after the solar energy system is constructed, it restricts the uses of adjacent land. A structure that would cast a shadow on the solar collectors could not be built. Thus, close attention to the master plan is warranted in accomplishing solar energy projects.

Aesthetically, there will be some who appreciate solar collector arrays associated with facilities, and there will be others that do not. Architecturally, much can be done with solar collectors mounted on the roof, but there is little potential for those mounted on the ground.

Some undesirable occupant maintenance may be required that has heretofore not been associated with conventional heating systems. It is possible that snow and ice may have to be manually removed from the solar collector arrays. Experience to date at the Air Force Academy Solar Test House showed that in the majority of instances, the solar collectors quickly cleaned themselves. Nevertheless, occasional situations did arise where this was not the case. Snow preceded by ice, and snow buildup on the roof such that the passage of snow clearing the collectors was blocked, are two cases in point (Reference 23). Arguments could be made for and against this clearing problem being the responsibility to clear occupants driveways and walkways of snow, but at the same time, if the collectors are mounted on the roofs, they would not want home occupants responsible for the clearing because of safety considerations. Certainly, buildings other than family housing would be cleared by the installation engineers.

One final potential problem worth noting involves the impact a solar energy system applied to a family housing unit might have to the life-style of the occupants of the home. If the project is a retrofit, there is a good opportunity that some of the mechanical equipment or the thermal storage tank (especially if it is a crushed rock/air system) will consume existing usable floor space. With space being a serious issue with family housing occupants today, such action may not be greeted positively.

Solar energy systems may require excessive tuning and adjustment as they are first put into operation. In addition, such a facility may be the subject of many visits by installation visitors because of its uniqueness. The result will be frequent interruptions to the family. Should the home be a part of a demonstration program or supporting an R&D effort, the family may have to perform functions supportive of the instrumentation system and may also be asked to act in some manners apart from their established life style. Hopefully, housing officials will consider these aspects as they assign solar energy system homes to their occupants.

In summary, some possible environmental effects of solar energy systems have been presented here. Certainly solar energy systems have an overall positive effect on the environment. Nevertheless, under some situations they could produce some negative effects as well. All effects must be considered. In time, as we gain more experience with solar energy systems from our ongoing programs, we will be able to better address the important issue of environmental impact.

SECTION XIII

THE AIR FORCE SOLAR ENERGY PROGRAM

Although not formalized as such, the Air Force has a burgeoning solar energy program of wide variety albeit conventional applications at many locations and under a variety of sponsorships.

At the Air Force Academy as a part of their solar energy program, a unit of military family housing was retrofitted with a solar energy system in 1975 (Reference 39). The purpose of this application was space heating and domestic hot water preheating. This project is an applied research and development project and, as such, is presently sponsored by the Air Force Civil and Environmental Engineering Development Office. Two housing units with the same floor plan and solar orientation are involved. One house has received the solar modification and the other serves as the performance reference. Both houses are carefully instrumented to support this experimentation. A computer is installed in the modified house to receive the information from the instrumentation sensors and to operate the various solar energy subsystems in accordance with preprogrammed instructions. The modified house features a split solar collector array with half the commercially manufactured collectors (273 square feet) located on the roof and the other half located on the ground adjacent to the house. Both houses have approximately 2000 square feet of floor space. A meteorological monitoring system which includes a pyranometer for measuring solar insolation, and devices for measuring wind speed, wind direction, and air temperature have also been installed adjacent to the modified house. The data that these instruments generate are collected by the project's computer.

A test and evaluation program is currently planned to run until 1979. During this period a number of experiments will be performed associated with operating the system in different configurations as well as modifying the system itself. Annual technical reports will be prepared to report on the performance (Reference 23).

The Solar Heating and Cooling Demonstration Act of 1974 requires a number of demonstration projects to be carried out on Federal property. The purpose of this action is to demonstrate to the public the effectiveness of solar energy systems. In accomplishing this, a number of solar energy systems will be experimented with and hopefully a private sector energy market will emerge with an industry to support it. Much of this demonstration work is being carried out within the Department of Defense in cooperation with the Energy Research and Development Administration, now the Department of Energy. For example, the Army and Air Force Exchange Service is pursuing a program of solar energy application. The new base exchange facility currently under construction at Kirtland AFB NM, as well as the same facility planned for Randolph AFB TX, will be heated and cooled by solar energy. The funds for these solar energy systems are provided by ERDA (now the Department of Energy). The scope of work involved in these two projects represents one of the largest undertakings of its kind to date. The Kirtland AFB facility will have 43,000 square feet of floor space and 8,000 square feet of solar collectors. The Randolph AFB facility similarly will have 60,000 and 12,500 square feet, respectively. In the future the new base exchange at Bolling AFB may also receive a similar solar energy system.

Other projects involving the use of solar energy systems that are directly Air Force sponsored include: a solar heated domestic hot water system for the chapel at Hickam AFB HI; a solar heated domestic hot water system for dormitories at Edwards AFB CA, Eglin AFB FL, McConnell AFB KS, Luke AFB AZ, and Cannon AFB NM; a solar heated domestic hot water system for 40 family housing units at Gila Bend AFS AZ; a similar application at Homestead AFB FL; and a solar assisted heat pump application for space heating and cooling family housing units at Little Rock AFB AR. Two other projects of somewhat different application include a photovoltaic application for cathodic protection at Wright-Patterson AFB OH, and wind energy project at F E Warren AFB WY for the generation of electric power. This latter project incorporates a 45-foot-high tower and a 15-kilowatt turbine. This program is very dynamic and as a result may be incomplete. The projects listed have a mixed status that ranges from that of a feasibility study to under construction. The Air Force is moving ahead slowly but surely as it awaits further expertise and availability of commercially manufactured products, as well as specifically dedicated funds.

In closing, it is important to realize that our sister services, the United States Army and the United States Navy, are also moving ahead with their own solar energy programs. The Army has built an experimental solar house at its Construction Engineering Research Laboratory at Champaign IL that applies solar energy technology for not only space heating, but also air conditioning. The Navy plans to construct its own such facility shortly at its Civil Engineering Laboratory at Port Hueneme CA. As previously described, the current DOD effort in photovoltaic applications is largely being accomplished by the Army under the MAPS program.

SECTION XIV

POSSIBLE MILITARY APPLICATIONS

The current solar energy program within the Air Force, with few exceptions, shares much in common with the programs common to the private sector; that is, application to residential dwellings and administrative and commercial buildings. If there is any major difference, it is that more emphasis is being given to retrofit schemes in the Air Force than in the private sector. The reason for this interest in retrofit schemes by the Air Force is because of its largely fixed real property base. The common applications being pursued are space heating, air conditioning, and domestic hot water heating. The projects being accomplished are either demonstration grant projects or normal projects that must amortize themselves. The former type of projects need not economically justify themselves. They are accomplished to establish consumer confidence and to assist the emerging solar energy equipment industry. The latter type of projects must economically justify themselves. The economic justification of these projects is approached on the basis of a scenario in which they are amortized by the savings accrued in the fossil fuels they offset. In many cases, this is difficult to justify today, and works against the more rapid development of solar energy systems. Nevertheless, this important work goes on as it must, as we all are anticipating much higher costs of fossil fuels in the future. Even worse perhaps is the situation where fossil fuels become unavailable either temporarily or permanently leaving no alternative but other energy sources such as solar energy. With this in mind, perhaps we should consider of the military because of its uniqueness might not be a fertile area for applying some areas of solar energy technology right now that the private sector might have to pass up.

One military application that might show promise would be applications that support tactical operations. With the renewed emphasis within the military being shown in the readiness/mobility concept and the necessity to be able to respond to limited war scenarios quickly and effectively, the conventional economic constraints applied against the more conventional solar energy facility applications may not be applicable. Thus, we need to consider whether or not current solar energy technology could effectively support our Bare Base Program (References 40 and 41). A review of the Bare Base energy requirements to support various deployment schemes shows that the energy requirements are represented as electric power in the hundreds of kilowatts range (References 42 and 43). Unfortunately, solar energy technology has not yet advanced to this order of magnitude. Nevertheless, the work being accomplished by MERADCOM (described elsewhere) which involves the investigation of the terrestrial military applications of photovoltaic systems is a positive step in support of some Bare Base requirements.

Previously, it was believed that a structure similar to the solar collector panel ground array as used at the Air Force Academy Solar Test House would have applications supportive of Bare Base (Reference 23). This belief was based on: the ability to adjust the sun angle of this structure so that it could be used in any latitude for any purpose, its ability to be prefabricated and relocatable, and the belief that it could be made air transportable. In retrospect, however, this type of structure might not be as well suited as earlier thought. It would certainly require backup by the conventional diesel generator system and as a result would increase the initial utility system equipment to be deployed. Its only real savings would occur in lessening the fuel resupply requirements that would be needed after deployment. Nevertheless, such a structure as the solar collector panel ground array could have excellent military application for remote sites requiring space heating, hot water, or air conditioning where the critical logistics issue is fuel resupply and not rapid airmobile deployment.

To summarize the probable applications of solar energy systems to tactical military operations, it appears that due to current equipment configuration, the greatest demand for energy is in the form of electricity and not heat. Although interest in the terrestrial application of photovoltaic systems is currently very active, the power requirements are still an order of magnitude away from satisfying operational requirements. Although work is currently underway to provide the military with a 60 kilowatt array photovoltaic cell which hopefully will weigh no more than 5700 pounds and produce electric power at four dollars per watt (Reference 44), the peak demand of a deployed Bare Base with maximum strength still remains at 9300 kilowatts. In view of this, perhaps complementary work involving wind/turbine and parabolic collector/steam turbine systems should also be pursued. The current Bare Base equipment packages are highly air conditioning oriented. Should requirements shift more to favor heating, flat plate solar collector arrays may prove to be feasible depending on the logistics constraints imposed.

There are some unique applications of solar energy technology, although not tactically oriented, that may nevertheless be very applicable to the military. All of these are associated with heating water. Rather than using this water for space conditioning where quality control and system tolerances are so critical, it could be used, at a lower initial cost, to heat water for swimming pools, aircraft washracks, and perhaps even wastewater treatment facilities.

The technology for heating outdoor swimming pools with solar energy is not only developed but is also on the low end of technology sophistication. Outdoor swimming pools at many installations, especially those at temporate climate locations, are a key morale, recreation, and welfare facility. This point does not need further edification. Nevertheless, should more stringent conservation matters become necessary, a finer line between mission essential and nonmission essential facilities may have to be defined. Under this condition, energy required to heat the outdoor pools may have to be diverted. A solar heating system could not only effectively sustain the outdoor pools but might also be able to extend their annual operating season as well.

For the past 10 years the Air Force, as well as all the Department of Defense, has made major efforts at improving environmental quality. As a part of this effort, many wastewater treatment plants have been identified as needing upgrading as effluent standards become more stringent. The majority of wastewater treatment plants in the Air Force that handle domestic sewage are trickling filter systems. These plants provide secondary level treatment via a combination of settling and biological oxidation unit operations. There is some evidence that the biological oxidation process that occurs in the crushed rock beds of the trickling filters is adversely affected by temperature drops of the effluent during treatment in the winter months (Reference 45). Such action has an adverse effect on the plant's performance which is manifested in a lower quality effluent. One response to this situation has been to construct domes over the trickling filters to help insulate the beds from the adverse chilling effects of the cold air. Perhaps a solar energy system could be incorporated with the domes that would heat the wastewater and thus increase the reliability of the biological oxidation process and provide a better quality effluent.

In conclusion, there are other applications of solar energy beyond the conventional applications such as space heating, air conditioning, and domestic hot water heating that may be applied to satisfy military requirements. Certainly these conventional applications are the most important and should be vigorously pursued. Nevertheless, because of the peculiar requirements of the military, there may be other applications that have merit. Some of those applications have been suggested here. Planners and programmers will innovate many more applications in the future.

SECTION XV

SELF-INVOLVEMENT

If your installation does not have an ongoing solar energy program and desires to develop a suitable background to support one, the information presented here may be beneficial.

Perhaps the first necessary step is to build a library. Because there is such a tremendous quantity of literature available on the subject today, it is logistically unrealistic to provide a recommended bibliography. Nevertheless, the list of references here is a start and is fairly Air Force oriented. The organizations listed below are good sources of information for a wide range of information.

International Solar Energy Society
American Section
300 State Road, No 401
Cape Canaveral FL 32920

American Society of Heating, Refrigeration, and
Air Conditioning Engineers (ASHRAE)
345 East 47th Street
New York NY 10017

The Solar Energy Institute of America
PO Box 9352
Washington DC 20050

National Solar Heating and Cooling
Information Center
Box 1607
Rockville MD 20850

The first three of these organizations provide not only membership opportunities, but also periodic publications and newsletters which contain much useful information on solar energy. In addition, there are some private publishing firms that offer reprint services. The National Solar Heating and Cooling Information Center can provide you with detailed bibliographies. They are a part of the Franklin Institute and are funded by the Department of Housing and Urban Development. Additionally, they may be reached by the toll-free telephone number (800) 523-2929.

Once you have initiated a general information library, you may next want to build a library of manufacturers' literature. The sources just mentioned may be able to provide you some catalog sources and list of manufacturers. Moreover, the Catalog on Solar Energy Heating and Cooling Products previously referenced (Reference 26) can also be useful for this purpose.

With an active library you may next want to tour a solar energy system house. Because of the great number that exist today, it is not logistically feasible to provide a listing. If you don't know where the closest one is located, you might contact your local utility company, one of your local engineering society chapters, or a nearby university for assistance. A tremendous amount of information can be gained by seeing a system in operation and talking directly to those responsible for it.

Having progressed this far, you may now be seriously considering just where and how solar energy systems may be applicable to the needs of your installation. Before you can progress any further you will need to acquire data on the solar insolation available. If local weather stations, universities, or government agencies cannot provide you any assistance, you may need to install a pyranometer and gather this information yourself before you do anything else. You should attempt to avoid using interpolated or contoured data as a basis for justifying project feasibility except under the most serious circumstances.

The importance of energy conservation measures, done in conjunction with solar energy system applications, cannot be stressed enough. By employing sound energy conservation measures, the heating and/or cooling load of a facility will be diminished and thus will be the amount of solar energy equipment needed. The overall result will be a lower cost project.

In support of energy conservation and the design of the solar energy system is the requirement to know very closely the magnitudes of the facility heating and cooling demands under specified conditions. Unfortunately, the accuracy of these demands requires more than calculations. Because installations' utilities are normally provided on a commercial basis, individual facilities are seldom metered. Yet, the most accurate way to determine these thermodynamic demands is via utility metering. Thus, it may become necessary to select a series of typical facilities that are being considered for solar energy system modification and meter their utilities in order to develop a very accurate data baseline of thermodynamic demand.

To further support a utility metering program you may also wish to incorporate thermography studies using infrared technology. This technique can help you overcome serious deviations between a specific facility and its as-built drawing. This technique will specifically identify areas of high energy loss in a facility very quickly.

The importance of developing an accurate data base of facility thermodynamic demand will be realized as you begin to develop your alternate energy projects. A sound data base will not only support a realistic economic analysis, but it will also support the design itself. Each solar energy facility application should be separately designed based on the exact qualifications of available solar radiation, thermodynamic demand, and the performance of the components to be used. Definitive designs and site adaptations should be avoided.

Now armed with a solar energy library, manufacturers' brochures, and a sound data base for your installation, the next step is to put it all together in the form of a series of projects. There is a fine line between planning and programming, and design. To help you in the design function you may want to review Solar Heating of Buildings and Domestic Hot Water previously referenced (Reference 27) or the article "Solar Energy Applications" which appeared in the Engineering and Services Quarterly last year (Reference 46). In addition, many colleges are now offering courses in solar energy technology and some engineering societies are sponsoring conferences, symposia, or short courses.

These courses and symposia are not restricted to the private sector alone. The Air Force has participated in similar areas. At the Air Force Academy for the past two years, the course Solar Energy Applications has been offered by the Department of Civil Engineering, Engineering Mechanics, and Materials. Last year (February 1976) the Air Force Institute of Technology's School of Civil Engineering at Wright-Patterson AFB hosted the USAF Alternate Energy Workshop.

Where can you turn for help and information on solar energy technology in the Air Force? The following listing is a partial source.

Civil and Environmental Engineering
Development Office (CEEDO)
Det 1 HQ ADTC (AFSC)
Tyndall AFB FL 32403

The Air Force Civil Engineering Center
Director of Facilities Systems
AFCEC/DE
Tyndall AFB FL 32403

Headquarters Army and Air Force
Exchange Service
Director of Engineering and Services
AAFES/EN-S
Dallas TX 75222

AFIT SChool of Civil Engineering
Director of Engineering
AFIT/DET
Wright-Patterson AFB OH 45433

The Principal Investigator
USAFA Solar Energy Program
Department of Civil Engineering,
Engineering Mechanics, and Materials
DFCEM
USAF Academy CO 80840

The Course Director
Solar Energy Applications (CE 495)
Department of Civil Engineering,
Engineering Mechanics, and Materials
DFCEM
USAF Academy CO 80840

SECTION XVI

CONCLUSIONS

The purpose of this report has been to provide you, the Air Force civil engineer, some useful information for the planning and programming of solar energy systems to satisfy some of your facility energy requirements.

Initially much attention was devoted to trying to explain the current energy situation. Almost everyone will agree today as to the seriousness of this situation. However, there are few who agree on how much energy is left or what the solution to normalizing the situation should be. The data presented here have attempted to consider all extremes, and as a result should be treated only as estimates. No doubt, if more energy exploration is accomplished, more energy reserves will be found.

Probably what is most important is to note the trends in consumption and demand as well as the relative amounts of energy remaining in conjunction with its irregular world distribution that prevails. Although energy conservation measures are very important, all they will probably do in the long run is balance out the rate of increased use as the number of energy consumers grow. The United States, with its tremendous per capita energy consumption, will probably continue on at the same high level as Americans will not be inclined to change their lifestyle voluntarily unless serious external forces require it. Rather, what will probably occur is that many remaining segments of the world will increase their level of lifestyle and consumerism until they equal us. This will result in even a greater demand being placed on world energy supplies.

The major lesson from all of this is for us to recognize now that there will probably be some marked changes in our energy sources. For the next 100 years, surely our energy base will continue to be fossil fuels. Although we rely predominantly on oil and natural gas today, these sources will probably peak in the next 25 years and we will then shift to a coal based fossil fuel economy supplemented by alternate and relatively exotic energy sources such as nuclear and solar energy. We will have to rely on our technology to continue to guarantee our viability as a world power.

How much solar energy contributes to our energy economy remains to be seen. Not only will its contribution rely heavily on external market conditions, but just as important, how well we actually use it. We in the Air Force are concerned about the future of our energy economy for a number of reasons. First, we are concerned because energy costs represent about half of our Air Force civil engineering operating budget. Moreover, in the future this relationship could become even worse. Second, we are concerned because the very question of energy availability to our installations could determine whether or not we are able to perform our mission satisfactorily. Although not our primary mission per se, it is the responsibility of the Air Force to work in concert with the private sector and other segments of our government to develop alternate energy sources and to help achieve a stable energy economy for the United States. The promulgation and accomplishment of sound solar energy projects is a positive step in this direction.

There are many applications of solar energy technology. Space heating, domestic hot water heating, air conditioning, and electric power generation are the more conventional applications. Space heating, and to a lesser degree, domestic hot water heating, are the most common applications, and are the ones with which we have the most consumer experience. The two major shortcomings facing solar energy technology today are high costs relative to fossil fuels and a definition of useful system life in the field under consumer conditions. Until the latter is answered, economic analyses will be highly academic. An associated technical problem is generating sufficiently hot enough temperatures at high enough mass flow rates to satisfy facility system demands. Recent applications of solar energy systems in conjunction with heat pumps offer a means of overcoming this problem and show excellent potential.

Beyond the conventional applications common to the private sector that are equally applicable to the military, there may be certain other applications that may be justified not on the basis of conventional economic considerations but on the importance of mission accomplishment. Although currently not well suited for tactical uses such as with Bare Base, solar energy technology may be very well suited for certain remote site locations.

The subject of solar energy technology is very dynamic. The material presented here has tried to put it in perspective but in no way is all inclusive. We must recognize that in the current stage of application of this technology, many changes will occur in the future. Nevertheless, we cannot afford to wait in anticipation. Instead, we must begin to actively plan and program solar energy technology against some of our future energy requirements now. The key to our success will be both how well we match up our requirement with the right component of this technology and also how flexible we are in our work.

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